Pulsars: Observations of Spectra

Abstract. *Dynamic spectrograms of two of the recently discovered pulsating radio sources have been obtained. The data provide the instantaneous spectrum and the time-frequency history of the signals over a bandwidth of 3 megahertz.*

Two of the recently discovered (*1*) pulsating radio sources, or pulsars, have been observed at the Jet Propulsion Laboratory's Goldstone Tracking Station. The signals from these pulsars (*1, 2*) have extremely regular repetition periods, although the amplitudes within a pulse and from pulse to pulse vary erratically. The radio frequency of each pulse (*3*) decreases with time, following the dispersion relationship of electromagnetic propagation through a medium containing free electrons. Presumably the signals near the source contain a wide band of frequencies. Since the group velocity for waves in such a medium is less for the lower frequencies, the received signals have the form of a sliding tone, or whistle, with the higher frequencies arriving before the lower.

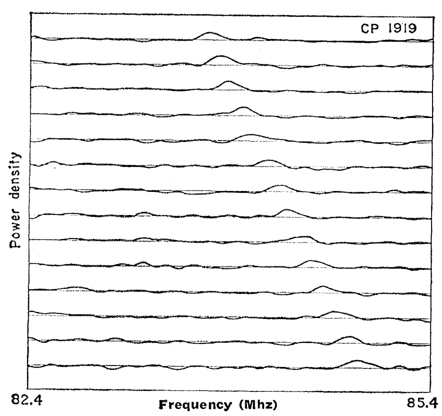

Fig. 1. Set of spectra of CP 1919, taken in successive 15.4-msec intervals and averaged over 1350 pulses.

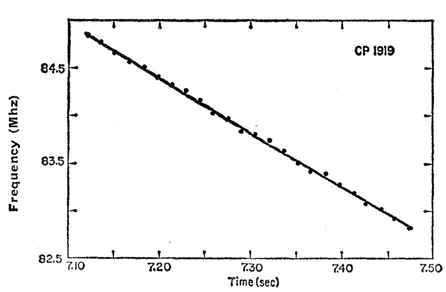

Fig. 2. Least-squares fit of the function $f = k/(t - t_0)^{1/2}$ to the data from CP 1919.

The familiar equation for index of refraction (*3*) is

$$n^2 = 1 - \frac{Ne^2/m\epsilon_0}{\omega^2 \pm (e/m)B\omega} \qquad (1)$$

where N is the electron density, ω is 2π times the frequency, e is the electron charge, m is the electron mass, ε_0 is the permittivity of space, and B is the component of any magnetic field along the line of sight. The choice of sign depends on the relation of the direction of the circularly polarized waves to the direction of the magnetic field.

This fact gives us the possibility of measuring directly the interstellar magnetic field, averaged along the line of sight. By observing the change of the time of arrival of the pulses with the antenna switched from left- to right-handed circularly polarized waves, one can obtain a measure of the field. Although this method is not as sensitive as the utilization of Faraday rotation (*4*), it does not require a polarized source.

The data collected are in the form of spectrograms of the signals. A bandwidth of 3 Mhz, centered at 84 Mhz, was investigated with a resolution of 50 khz. Time was divided into 15.4-msec slices, and an independent spectrogram was taken for each slice. Because of the periodic nature of the pulsars, the signal-to-noise ratio can be enhanced greatly by averaging together corresponding sets of spectra from many pulses.

A sample set of spectra from CP 1919 shows the time-frequency history of the signals, averaged over 1350 pulses (Fig. 1). Signals from CP 1919 enter the spectrograms from the high-frequency side and move rapidly through them toward the low. It follows from Eq. 1 that, if the observed effect is indeed caused by dispersion, the relationship between f and t is

$$f = k/(t - t_0)^{1/2} \qquad (2)$$

Table 1. Summary of observed pulsar characteristics.

Pulsar	Frequency (Mhz)	df/dt at 84 Mhz (Mhz/sec)	Integrated electron density (parsec/cm³)	Period (sec)
CP 1919	$226/t^{\frac{1}{2}}$	5.81	12.4	$1.3373008 \pm 3 \times 10^{-7}$
CP 0834	$231/t^{\frac{1}{2}}$	5.56	12.9	$1.2737620 \pm 3 \times 10^{-7}$

Table 2. Summary of observed pulsar characteristics.

Pulsar	Peak power density (watt hz^{-1} $m^{-2} \times 10^{-26}$)	Average power (watt/m^2 $\times 10^{-21}$)	Average bandwidth (khz)
CP 1919	63	49	77
CP 0834	53	36	69

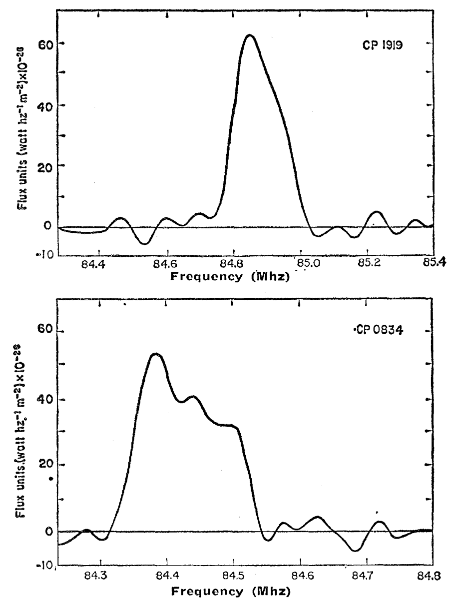

Fig. 3. Instantaneous spectrum of the average pulse of CP 1919 (top) and CP 0834 (bottom). Note the expanded frequency scale for CP 0834.

The data from each set of spectrograms were processed to determine the constants k and t_0 by the method of least squares. The central frequency of the pulse in each spectrum was obtained by convolving the data with the expected pulse shape—a maximum-likelihood procedure if the shape is perfectly known.

The results of the least-squares fit are given in Fig. 2. There is a close fit to the theoretical curve. At 83 Mhz, the pulse has been delayed (dispersed) by almost 7.5 seconds. Table 1 summarizes the values of k obtained, along with the corresponding frequency sweep rates and integrated electron densities.

From Eq. 1 it follows that the change in time of arrival, ΔT, that occurs when the mode of circular polarization is switched is

$$\Delta T = \frac{4(t - t_0)\, e\, B}{\omega\ m}$$

We found that the measured ΔT was not statistically significant for either source. However, an upper limit for the integrated magnetic field may be set. From the standard deviation of the time-of-arrival estimates (0.0006 second), that of the magnetic field measurement is found to be $\pm 0.62 \times 10^{-3}$ gauss.

The time-of-arrival measurements have also allowed us to determine the repetition period of the pulses to surprising accuracy. A very small difference of timing between the pulses and the signal-sampling equipment produces a cumulative drift of the time-frequency trajectory of the pulses. Our measurements, corrected for Earth's orbital velocity and rotation, are given in Table 1. For CP 1919, the period matches very closely that published in (*5*), in distinction to that in (*1*).

Using the best-fit relation (Eq. 2), we displaced each spectrum of a set to a common frequency origin and then averaged the spectra. Figure 3 (top and bottom) shows the spectral characteristics of the average pulse.

The frequency structure of these two sources is quite similar to the time structure already reported (*6*). They both have a basic triangular shape and sudden onset and termination. There was no evidence of any power outside of the main pulse.

The peak power density, average power, and average bandwidth of these pulsar signals are given in Table 2.

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7. We thank G. A. Morris, C. F. Foster, and S. A. Brunstein, respectively, for their excellent and effective work in constructing the wide-band spectrum analyzer, the radio receiver, and the antenna feed. Supported by NASA contract NAS 7-100.

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Morphology and Origins of Sedimentary Structures on Submarine Slopes

Abstract. *Submarine slopes in deep water, such as continental slopes, are often indented by valleys or channels and made uneven by ridges or levees. The origins of many of these features are unknown or disputed. Morphologically, however, there is often great similarity between forms on deep slopes and forms on shallow slopes or on land. Structurally the slopes in deep water are less well explored, but several observations reveal features, such as lamination and cross-bedding, that are known from shallow water also. Measurements of current indicate that periodically the movement of water near the bottom is fast enough to move particles of sediment from time to time. Morphology, fine structure, and currents suggest that internal waves and associated currents, as well as gravity, may control the shape of deep submarine slopes analogously to the shaping by surface waves of slopes in shallow water.*

In shallow water, the morphology and fine structure of sea-floor slopes are very strongly influenced by waves and associated currents. Observations of intermittent currents in the deep ocean seem to justify an attempt to relate topographic and structural forms of the sediment on the slopes to internal waves and currents associated with them. The making known of the unknown often depends on formulation of the right question; thus the purpose of this report is to ask whether the descriptions and explanations of the morphology of deep-sea slopes are furthered by suggestion of the existence of physical processes analogous to those in shallow water.

The many observations in shallow water (*1*) have led to some satisfactory hydrodynamic models relating water movement and particle transport. In shallow water (characterized in this discussion by the depth at which wind waves interact with the sea floor—generally shallower than 150 m), slopes are commonly inclined between 2 and 7 deg. Bars, troughs, terraces, and channels are some forms that can make slopes uneven; on a smaller scale, sand waves, ripples, or individual constituents of sediments may impose a surface roughness. Most topographic features are associated with distinct structures and textures of the sediment. One finds layers, laminae, and even preferred orientations of individual grains that indicate the movement of the water from which the sediment settled. Forms and structures are often very complex: for instance, a bar may be superimposed on a gentle slope, and superimposed on both may be ripples of more than one set. Thus a cross section shows different orientation of sets of laminae or of the constituent sand grains.

Waves, mostly generated by winds, and currents induced by them play the dominant role in modification of shallow-water slopes. Wave height and period are characteristic parameters, although they describe the waves only partially. Depth of water and type of bottom exert further control of what waves do as they travel up a slope. In a first approximation, analogies with ray optics can be made; thus water waves are known to be reflected, refracted, and diffracted somewhat analogously with light waves; interference patterns, resonance, and composite oscillations are some of the more complex but not uncommon resultant forms. Direct measurements are difficult. Fluctuations in temperature, as well as water motion, are often recorded at fixed points. Spectrum analysis is applied for production of information about the characteristic wave parameters.

As well as directly modifying shallow-water slopes, wind waves can establish longshore drifts of sediment when their fronts are not normal to the coast; such a drift is perhaps the largest single mechanism for sand transport nearshore. A peculiar short-periodic flow of water induced by waves is known as rip current; rip currents provide the return flow of water that has been "piled up" higher on the slope, and thus they carve channels sometimes more than 1 to 2 m in depth. Despite many attempts to describe the process, a detailed picture only now appears to evolve (*2*).

In deep water, major slopes such as continental slopes have similar inclinations, 2 to 7 deg, as have beaches and their shallow-water extensions; they have been studied much less intensively. The ever-increasing number and quality of echo soundings, direct observations by divers, and photography reveal ever more detail. As they become better known, the slopes appear less and less smooth. Not many years ago only the major submarine canyons were known or partly known; modern maps show submarine canyons on the slopes of all continents (*3*).

The frequency of smaller valleys and channels on a map often appears to be proportional to the intensity of bathymetric survey of the area. Probably the